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# FEASIBILITY OF TUNNEL DETECTION BY TRACE GAS ANALYSIS

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CORPS OF ENGINEERS, U.S. ARMY
COLD REGIONS RESEARCH AND ENGINEERING LABORATORY
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## PREFACE

This report was prepared by Dr. R.P. Murrmann, Research Chemist, Mr. D.C. Leggett, Analytical Chemist, and PFC T.F. Jenkins, Analytical Chemist, under the general direction of Dr. D.M. Anderson, Chief, Earth Sciences Branch. The authors are members of the Research Division of USA CRREL.

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# FEASIBILITY OF TUNNEL DETECTION BY TRACE GAS ANALYSIS

by

R.P. Murrmann, D.C. Leggett, and T.F. Jenkins

## INTRODUCTION

Detection of tunnels, bunkers, and caverns by chemical analysis should be possible, provided that trace gases in the atmosphere near access ports and vents are qualitatively or quantitatively unique to these tactical underground sources. Although the identity of the trace gases upon which a detection system could be based remains to be established, we visualize that volatile chemicals arising due to perturbation of biological and physical processes, or effluvia from man and his activities, will provide a suitable "chemical signature" detectable under a wide range of environmental conditions.

## BACKGROUND

During the past year, considerable progress has been made in obtaining information prerequisite to the development of a trace gas detector for underground cavities. Puerto Rico was selected for explosives detection and tunnel detection research. This choice was based primarily upon the unique availability of a wide range of environmental conditions within a remarkably small geographic area. A primary tunnel site (Laguna Joyuda) was selected near the city of Mayaquez, and all engineering criteria preliminary to the actual construction phase have been developed[2]. This tunnel will be suitable for trace gas detection research as well as for research and development activities related to all other types of detection principles. Descriptive[9], physical[2], chemical[10], seismic[13], and electromagnetic[12] characterizations of the soil at this site as well as other selected locations have been completed. Aerial photography of the site has been obtained and an environmental analysis of selected area in Puerto Rico by remote sensing techniques is in progress[7].

With specific regard to trace gas detection, both theoretical and experimental studies have been completed[3,5,6,11]. As a result we know that diffusion of signature chemicals through soil into the atmosphere can be regarded as unimportant compared to flow of air through ports and vents. A complete gas chromatography-mass spectroscopy laboratory has been assembled for identifying and quantifying trace gases associated with various sources or present in the atmosphere under different environmental conditions, and analytical procedures have been devised for their analysis. Preliminary analyses of atmospheric air and soil air collected from the Laguna Joyuda as well as other sites have been completed[5]. Carbon dioxide has been identified as a potentially useful signature chemical[4]. Plans are now being developed for a comprehensive trace gas analysis program, determination of feasibility of $CO_2$ detection, and investigation of tunnel outgassing characteristics upon completion of the construction phase of the tunnel. Determination of trace gases present in atmospheric air and soil air in other types of environments will be initiated.

The initial objective of the work reported in this study was to test experimental procedures developed for use in the trace gas analysis program. Air samples were obtained from the USA CRREL permafrost tunnel, Fox, Alaska, during the period 10-15 January 1970. The experimental results obtained demonstrate the feasibility of locating tunnels by trace gas analysis.

## EXPERIMENTAL APPROACH

### Site description

The USA CRREL permafrost tunnel at Fox, Alaska, was selected for this preliminary investigation primarily because of the immediate availability of both the site and support personnel. Another important factor was the presence of an odor unique to this tunnel which allows olfactory verification of experimental results. Although this site bears little physical or environmental resemblance to the typical SEA tunnel, it is likely that this type of installation would find common use in the event of a conflict in an arctic environment.

The geological characteristics of the tunnel have been described previously[4]. Its primary features are illustrated in Figure 1. After this illustration was prepared a shaft was extended from near Station 1+00 diagonally to bedrock[1]. The mean depth of the main tunnel shaft is about 35 ft. The tunnel ranges from 10 to 15 ft wide and from 6 to 12 ft high (Fig. 3) and is about 400 ft long. A ventilation shaft about 3 ft in diameter near the end of the tunnel (Fig. 4) opens to the atmosphere high on the hill beyond the tunnel entrance (Fig. 5). During the winter months the permafrost inside the tunnel is naturally refrigerated by circulation of ambient air. During the summer, a refrigeration system is used to maintain an internal air temperature of about –5°C.

### Micrometeorological measurements

Micrometeorological measurements were made to determine the relationship between the direction and speed of air movement in and out of the tunnel, and variations in meteorological conditions. Microbarographs to measure pressure, and hygrothermographs to measure relative humidity and temperature were installed inside the tunnel (Fig. 3) and outside near the entrance (Fig. 2) and the vent (Fig. 5). Wind speed and direction measurements were made outside near the vent using a standard wind vane anemometer recording system. The direction and speed of air movement through the vent were also recorded using a wind vane and anemometer.

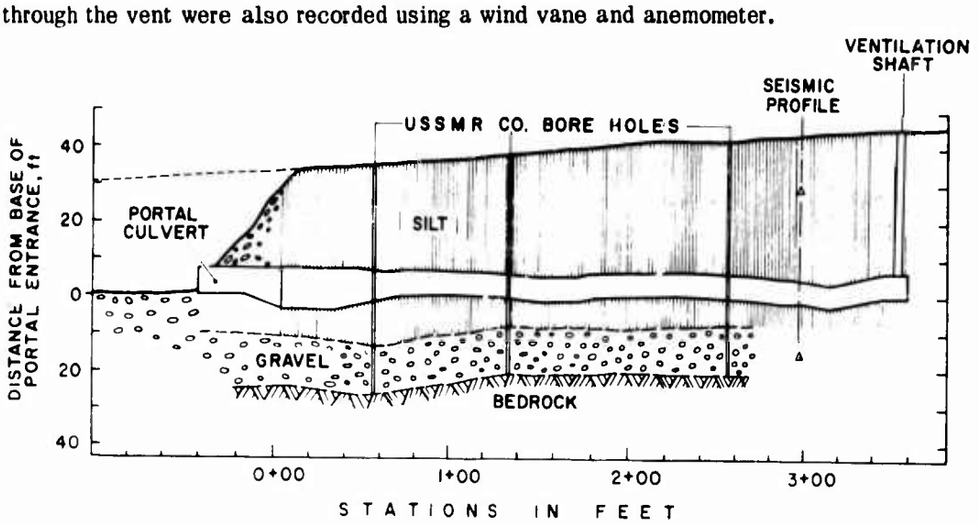


*Figure 1. Primary features of the USA CRREL permafrost tunnel, Fox, Alaska, (From Sellmann[5])*

Figure 2. Entrance, USA CRREL permafrost tunnel.

Figure 3. Primary shaft, USA CRREL permafrost tunnel.

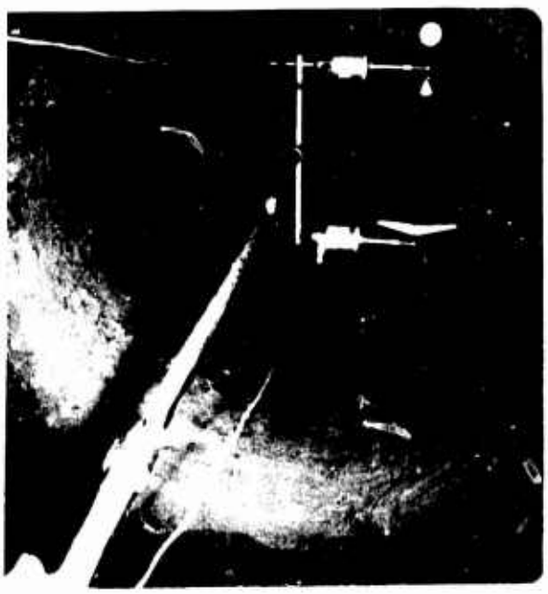

Figure 4. Inside view of ventilation shaft, USA CRREL permafrost tunnel.

Figure 5. Outside view of ventilation shaft opening, USA CRREL permafrost tunnel.

### Air sampling

Air samples were obtained on 14 January 1970 using evacuated, 3-liter, stainless steel cylinders which were filled over a period of about 30 minutes. Sampling locations included: inside the tunnel near Station 2+00 (Fig. 1, 3), upwind about 40 yards from the vent opening (Fig. 5), and downwind from the vent opening about 40 yards. The main doors at the tunnel entrance were closed several days prior to and during the period of sampling which greatly restricted air movement. The temperatures inside and outside the tunnel during sampling were about -10°C and -35°C, respectively. The surface wind speed measured near the vent opening was about 20 mph. The filled sampling cylinders were returned to USA CRREL for gas chromatographic/mass spectrometric analysis.

### Air analysis

Analysis of the air samples for trace components involved selective concentration of trace gases by cryogenic trapping, separation by gas chromatography, and identification by mass spectroscopy. During this procedure a cylinder containing an air sample was connected to a specially constructed chromatographic inlet system, and warmed using a heating mantle to about 180°C to desorb trace components from the cylinder walls. The cylinder was then pressurized to 30 psi using zero helium, and vented at 50 ml/hr through a $LN_2$ trap. Using this procedure nitrogen and oxygen passed through the trap while trace components were concentrated in the trap by a factor of more than $10^3$ relative to their original concentration in air. Next, the trap was heated to 180°C to vaporize trace components. Carrier gas was diverted through the trap, sweeping the contents to the head of a Porapak Q analytical column where most trace components were again condensed at -70°C. Following an isothermal hold period for 2 minutes, the column temperature was programmed at a rate of 8°C/min to a final temperature of 170°C which was held for about 30 minutes for elution of most major components. During preliminary work, a flame ionization detector was used for peak detection. For mass spectrometric analysis, peak elution was followed using a total ion current monitor. The procedure followed was free from the difficulties usually resulting from the presence of water vapor in the sample. The primary limitation is that large molecules with a molecular weight more than about 200 and some polar molecules are not detected.

## DISCUSSION OF RESULTS

Before describing the analytical results it seems worthwhile to elaborate on conditions which existed at the tunnel during the period of observation. Upon arrival at the tunnel site on 10 January, the front doors (Fig. 2) were open. The path of air flow was in through the front doors and out through the ventilation shaft (Fig. 4). The flow rate of air in the tunnel was not measured but can best be described as a "brisk breeze." Outside by the vent opening (Fig. 5) a slight but steady breeze persisted. As a result of these conditions the odor mentioned previously, which originates inside the tunnel, was concentrated outside in the vicinity of the vent. The odor was strong in the immediate vicinity of the vent and could be detected at least 200 yards downwind. It seemed that trace gases not readily detectable by scent might be readily detectable by the analytical techniques used.

The environmental conditions described above seemed heavily biased in favor of the possibility of detection. To provide a more realistic test, the tunnel doors were shut to reduce the volume of air venting to the atmosphere. It was also hoped that upon closing the door the direction and speed of air movement through the tunnel would become dependent upon local meteorological conditions. Accordingly, arrangements were made to collect meteorological data and the flow of

air through the tunnel was observed for several days. Although shutting the doors greatly reduced the speed of air movement in the tunnel, the direction of movement remained the same – out the vent. Daily variations in ambient temperature and atmospheric pressure had little influence on the air flow characteristics. This is thought to be due to dominating convective flow resulting from extreme differences between internal and external temperatures. The inside temperature remained constant at about -12°C while the outside temperature varied from about -40°C to -20°C. It is possible that the direction of air flow may reverse during the summer months when the ambient temperature greatly exceeds the inside temperature. Inasmuch as there seemed to be no relationship between tunnel-air flow dynamics and meteorological conditions, the meteorological data collected are not included in this report. We still feel that local meteorological conditions will influence tunnel outgasing in situations where convective flow does not predominate.

On the day of collection of the air samples, the front door was closed and the movement of air out the vent was much slower than that described above on the first day. Although air movement in the tunnel was hardly discernible, the tunnel was venting slowly but steadily to the atmosphere. Outside at the vent opening a wind speed up to 20 mph persisted. The odor of the tunnel was detectable directly over the vent but due to rapid dissipation and reduced air flow at the vent it could not be sensed even several yards downwind. Although these conditions seemed extremely unfavorable for detection of the tunnel, air samples were nevertheless collected at positions 40 yards both downwind and upwind from the air vent, and inside the tunnel.

Typical gas chromatograms of the air collected at the various positions are shown in Fig. 6. From top to bottom the chromatograms represent downwind air, upwind air, and tunnel air, respectively. About 40 separate chromatographic peaks were isolated for each of the samples. Most of the peaks shown are common to all of the samples. Although not shown, there were chemical compounds eluting at longer times in the tunnel-air and downwind samples which were not observed upwind. However, these peaks could be detected only at high sensitivity. The most striking differences observed are in the relative amounts of the individual components identified in the tunnel and detected in the downwind and upwind positions. The concentration of many of these components downwind was a factor of 10 to 100 higher than that in the upwind position. This can be seen by comparing the attenuation factors at which the chromatograms were obtained. In some cases, the concentration of a component downwind was higher than that observed in the tunnel. This is probably due to the fact that the tunnel gas was sampled near the center of the tunnel rather than at the more representative position near the end of the tunnel by the vent. Although not discussed in detail in this report, other air samples were obtained at the Poker Creek watershed, a remote area not in the vicinity of the tunnel. In this case, the concentrations of components in the air were lower than in even the upwind sample near the tunnel. For this reason, it is believed that the composition of the upwind air in the immediate vicinity of the tunnel is related to trace gas originating in the tunnel.

The identities of many of the trace components in the air samples are given in Table I. A variety of chemical classes is represented. The presence of the lightweight, fluorinated hydrocarbons is thought to be associated with the use of Freon-12 as a refrigerant in the tunnel during the summer. It is worth noting that the refrigeration system had not been in use for several months prior to sampling.

The relative concentration of selected compounds at the various sampling positions is given in Table II. As pointed out earlier, the downwind concentration of a given component is considerably greater than the upwind concentration. The apparent discrepancy between downwind concentration and concentration in tunnel air is most likely due to the position of air sampling within the tunnel.

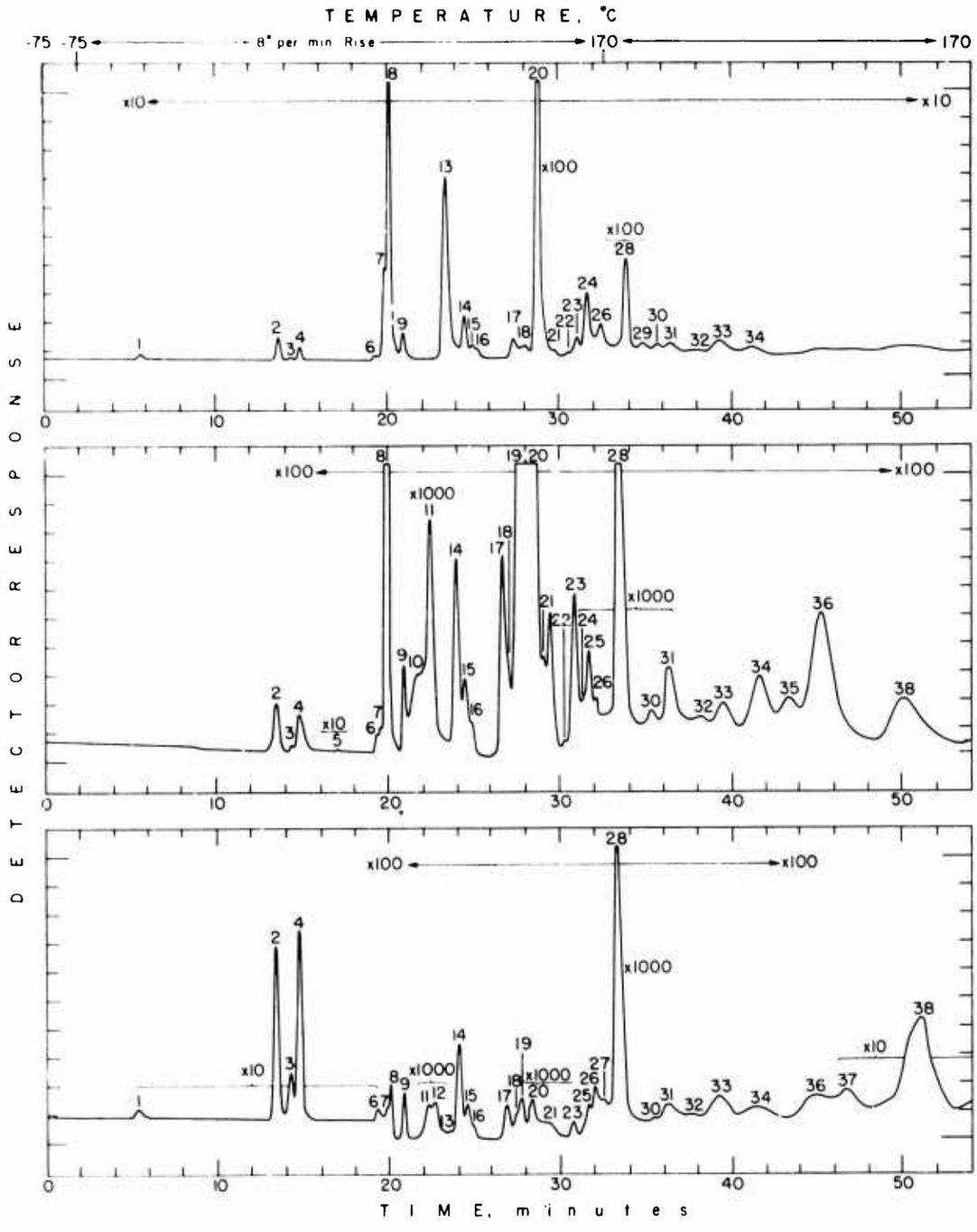


*Figure 6. Chromatograms of air obtained from USA CRREL permafrost tunnel, Fox, Alaska. From top to bottom: 40 yards upwind; 40 yards downwind; inside tunnel. Chemical compounds associated with peaks are identified in Table I.*

**Table I. Trace gases identified in air obtained from USA CRREL permafrost tunnel, Fox, Alaska.**

| Peak* | Chemical compound | Peak | Chemical compound |
|---|---|---|---|
| 1 | Methane | 20 | Acetone |
| 2 | Ethylene | 21 | Pentene, Pentyne |
| 3 | Acetylene | 22 | Isopropanol |
| 4 | Ethane | 23 | Methyl acrolein |
| 5 | | 24 | Chloroform |
| 6 | | 25 | Butanol |
| 7 | Propene, $CHF_2Cl$ | 26 | Methyl ethyl ketone, cyclopentanone |
| 8 | Propane, $C_2F_3Cl$ | 27 | |
| 9 | $CH_3Cl$, $CF_2Cl_2$ | 28 | Benzene, $C_2HCl_3$ |
| 10 | | 29 | |
| 11 | | 30 | |
| 12 | | 31 | 2-Pentanone |
| 13 | Acetaldehyde, methanol | 32 | |
| 14 | Butene | 33 | |
| 15 | Butane | 34 | Toluene, $C_2Cl_4$ |
| 16 | $C_2H_5Cl$ | 35 | |
| 17 | Ethanol, Furan, $C_2Cl_2$ | 36 | |
| 18 | Carbon disulfide | 37 | |
| 19 | Propanal | 38 | |

* Peak numbers correspond to peaks labeled in chromatograms in Figure 6.

**Table II. Relative concentration of selected trace gases present in air obtained from USA CRREL permafrost tunnel, Fox, Alaska.**

| Peak* | Chemical compound | Detector response† ($10^{-12}$ amp) upwind | downwind | tunnel |
|---|---|---|---|---|
| 2 | Ethylene | 4 | 90 | 30 |
| 4 | Acetylene | 2 | 70 | 30 |
| 9 | $CH_3Cl$, $CF_2Cl_2$ | 5 | 150 | 80 |
| 14 | Butene | 6 | 320 | 160 |
| 17 | Ethanol, Furan, $C_2Cl_2$ | 3 | 360 | 60 |
| 23 | Methyl acrolein | 3 | 260 | 30 |
| 31 | 2-Pentanone | 2 | 910 | 30 |
| 34 | Toluene, $C_2Cl_4$ | 2 | 90 | 20 |

* Peak numbers correspond to peaks labeled in chromatograms in Figure 6

† A detector response of $5 \times 10^{-12}$ amp is equivalent to a full scale peak at the highest sensitivity of the instrument. For a given compound, detector response is proportional to concentration; however, detector response varys somewhat for different compounds. Minimum detectable level of hydrocarbons is about $5 \times 10^{-12}$ g/sec.

As a result of this investigation it seems clear that it is possible to locate underground cavities such as tunnels by detection of associated trace gases in the atmosphere. What is now needed is an understanding of the types of trace gases unique to tunnels in different environmental locations so that a detection system for specific chemical signatures can be devised. The relationship between meteorological conditions and tunnel outgassing must be investigated so that the proper times to detect tunnels by trace gas analysis can be predicted.

## LITERATURE CITED

1. Dick, R.A. (1969) Evaluating blasting techniques in frozen gravel. *Mining Congress Journal*, Sept.

2. Grabau, W. Private communications. U.S. Army Engineer Waterways Experiment Station.

3. Leggett, D.C., Murrmann, R.P. and Anderson, D.M. (1969) Adsorption of acetone by soil from Laguna Joyuda tunnel site. U.S. Army Cold Regions Research and Engineering Laboratory (USA CRREL) Technical Note (unpublished).

4. Murrmann, R.P. (1969) Status report: Mine and tunnel detection by trace gas analysis. In *Compendium of OCRD Coordinating Conference for Barrier-Counterbarrier Research.*

5. _____ (1969) Progress report on mine and tunnel detection research. Research Division, USA CRREL, 1 October-31 December (unpublished).

6. Nakano, Y., Murrmann, R.P. and Anderson, D.M. (1969) A theoretical analysis on migration of volatile chemicals in earth media: Application to detection of mines and tunnels by trace gas analysis. USA CRREL Technical Note (unpublished).

7. Rinker, J. Private communications. USA CRREL.

8. Sellmann, P.V. (1967) Geology of the USA CRREL permafrost tunnel, Fairbanks, Alaska. USA CRREL Technical Report 199.

9. Simpson, T. and Murrmann R.P. (1969) Description of soils at mine-tunnel detection research sites, Puerto Rico. USA CRREL Special Report 144.

10. _____ (In press) Chemical properties of soils at mine-tunnel detection research sites, Puerto Rico. USA CRREL Special Report 147.

11. _____, Nakano, Y. and Murrmann, R.P. Diffusion of trace gases in soils from explosives – tunnel detection sites, Puerto Rico. USA CRREL Technical Note (in preparation).

12. Walker, J. Private communications. U.S. Army Electronics Command.

13. Wallen, J. Private communications. U.S. Army Mobility Equipment Research and Development Center.

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13. ABSTRACT

The feasibility of tunnel detection by trace gas analysis was investigated at the USA CRREL permafrost tunnel near Fox, Alaska. Under favorable conditions, the presence of an odor unique to the tunnel could be sensed at least 200 yards downwind from the air vent. Under extremely unfavorable conditions, trace gases identified in the tunnel were present 40 yards downwind from the air vent in concentrations 10 to 100 times greater than were observed upwind. These results support the principle of detection by trace gas analysis.

14. Key Words

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